IAEA-CN-70/108

RADIATION PORTAL EVALUATION PARAMETERS

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Abstract

The detection of the unauthorized movement of radioactive materials is one of the most effective nonproliferation measures. Automatic special nuclear material (SNM) portal monitors are designed to detect this unauthorized movement and are an important part of the safeguard systems at US nuclear facilities. SNM portals differ from contamination monitors because they are designed to have high sensitivity for the low energy gamma-rays associated with highly enriched uranium (HEU) and plutonium. These instruments are now being installed at international borders to prevent the spread of radioactive contamination and SNM. In this paper the parameters important to evaluating radiation portal monitors are discussed.

1. Introduction

Automatic pedestrian and vehicle portal monitors have been an established tool for controlling the movement of radioactive material at US nuclear facilities for 15 years. The technology of automatic pedestrian and vehicle monitors was developed at Los Alamos National Laboratory (LANL) in the 1970s and early 1980s.[1,2,3] These monitors were specifically designed to detect the presence of special nuclear material (SNM) by comparing the gamma-ray and neutron intensity while occupied to the background radiation level which is measured while the monitor is unoccupied. The measured gamma-ray background level is used to update the alarm threshold to maintain a constant false-alarm rate. SNM portals differ from contamination monitors because they are designed to have high sensitivity for the low energy gamma-rays associated with highly enriched uranium (HEU) and plutonium. SNM monitors are highly effective contamination monitors but contamination monitors are not necessarily effective SNM monitors. SNM portals generally consist of two vertical cabinets containing both large plastic scintillators and decision-making electronics.

SNM monitors were designed to control the unauthorized movement of SNM at nuclear facilities. Radiation monitors used to control the movement of radioactive material across international borders do not require the same sensitivity as those at nuclear facilities. Although some effort will be required to tailor these instruments to this new application, the effective operation will depend on the same operational parameters.

2. Important Parameters

The purpose of a radiation portal monitors is to detect the presence or movement of radioactive material. Therefore, the sensitivity should be quoted not at its most sensitive area but, at its least sensitive area. That is, what is the largest amount of radioactivity that can pass through the monitor without being detected. To evaluate a monitor, its sensitivity should be mapped to determine the region of least sensitivity. Figure 1 shows a vertical profile for a portal monitor using plastic scintillators as detectors. Although there is a drop in sensitivity in the vertical center of the portal, the regions of least sensitivity are at the bottom and the top of the monitor. For pedestrian monitors, the region of least sensitivity is the bottom of the monitor because the measurement time for a person's foot passing through the monitor is less than the rest of the body. After the region of least sensitivity has been determined, horizontal sensitivity plots, which simulate vehicle or pedestrian passage, can be used to determine the smallest detectable amount of radioactivity. An example of this plot is shown in Figure 2.

Determining the sensitivity for vehicle monitors is more difficult because the amount of shielding available varies for different vehicles. However, the potential for shielding is greatest near the engine block and the vehicle axles. Therefore, the sensitivity should be quoted for sources placed in these areas. This is why a simple truck bed monitor which monitors contaminated steel is not necessarily an effective radiation monitor for a border crossing.

The comparison of radiation monitors is difficult because the proper quotation of sensitivities is very complicated. When quoting instrument sensitivities, the false alarm rate and the radiation background level must be quoted. The detection thresholds of contamination monitors are normally quoted in dose rate in μSv/h while SNM monitor sensitivities are quoted in terms of the minimal detectable mass of SNM. A quote in μSv/h must include the gamma energy and the distance between the source and the instrument. Instruments that read in μS/h are calibrated for one energy (usually ^{137}Cs) and a correction must be applied for all other energies. A quote of the minimum detectable mass must include the isotope, the enrichment, and the form and the shape of the material. The form and shape of SNM is important because the material is extremely self-absorbing. Thin sources, powders, or foils emit most of their radiation whereas more compact shapes such as metallic spheres and cylinders reabsorb 90% of their radiation. Therefore, if a manufacturer quotes a minimal detectable mass of 10g without stating the physical form of the material, the uncertainty in the sensitivity is more than a factor of 10.

A very important step in the evaluation of any monitor is measuring the monitor's false-statistical alarm rate because the detection sensitivity is closely related to this value. This requires interrupting the monitors occupancy sensor automatically for short periods (1 minute or so) of occupancy and allowing the background level to be updated between test periods. The key to the detection of SNM is to achieve a lower level discriminator setting that allows for the detection of low energy gamma's without counting significant electronic noise. A small amount of electronic noise can significantly effect the false-alarm rate. Therefore, the false-alarm rate must be measured rather than merely calculated. To establish the false-alarm rate for an alarm threshold of 4σ, which has a calculated false alarm rate of 1 in 30,000 tests, approximately 0.5 million tests are required. Results of the false alarm testing should fall within a factor of 2 of the calculated value if the electronic noise level is not contributing significantly to the rate.

Besides the sensitivity of the detector, the detection algorithm is also important. In walk-through pedestrian monitors, pre-counting and post-counting capabilities are important. That is, the monitor should include counting time prior to being occupied and after it has been occupied as part of its decision making process. These capabilities are important because it greatly reduces the effects of body shielding.

For comparing plastic scintillator based monitors, their sensitivity to a particular isotope can be determined by using a signal-to-noise ratio as a figure-of-merit (FOM). A larger FOM indicates better performance. The signal used is the net count produced by the desired isotope positioned at an appropriate location on the monitor. The net count, S, is calculated by subtracting a background count, B, from the total count, S + B, measured with the source positioned in the monitor. The background count, B, is measured with no source present. The noise used in the FOM is the statistical variation in the background measurement. For gamma-ray monitors, the statistical variation can be estimated by the $\sqrt{B}$, which is the standard deviation of the measurement. The ratio of S to the $\sqrt{B}$ shows how large the net signal is in comparison to the normal statistical variation in the monitor's background measurements. Hence, obtaining the largest possible FOM without increasing the statistical false alarm rate, is directly related to obtaining the best performance.

$$FOM = S/\sqrt{B}$$

This FOM is very useful for comparing the detection threshold of different monitors for the isotopes of interest.

3. Conclusion

Selecting the best radiation monitors to prevent the transportation of radioactive materials across international borders is not a simple task. The nuisance alarm rate must be low enough to not significantly impede the normal flow of traffic. A nuisance alarm is an alarm which the result of material with normal or internationally acceptable levels of radioactivity passing through the portal and triggering an alarm. Achieving an acceptable nuisance alarm rate and still having sufficient sensitivity to deter the proliferation of nuclear weapons is a challenging endeavor. Only with the careful selection of the operating characteristics of the radiation portal monitors and the use of sophisticated portable isotope identification instruments is this goal achievable.

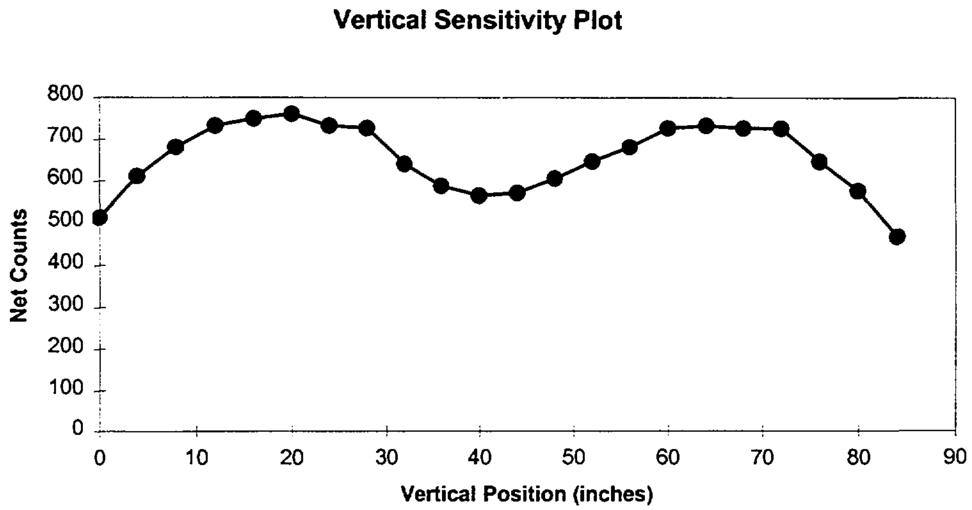

Figure 1. A vertical sensitivity plot to determine the region of least sensitivity.

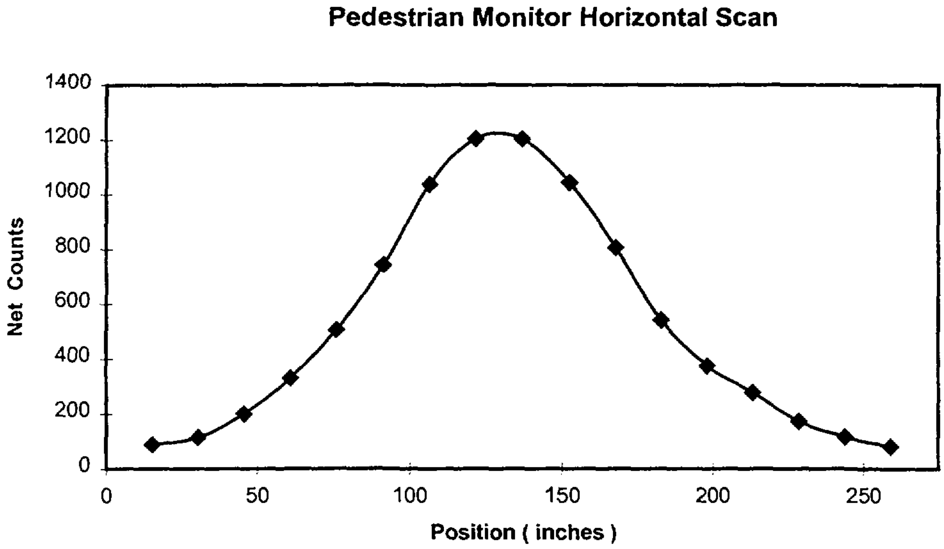

Figure 2. A horizontal sensitivity plot to calculate the minimum detectable sensitivity.

References

[1] FEHLAU, P. E., An Applications Guide to Pedestrian SNM Monitoring, Los Alamos National Laboratory, Rep. LA-10633-MS (February 1986).

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[3] FEHLAU, P. E., 1990 Update for the Applications Guide to Pedestrian SNM Monitors, Los Alamos National Laboratory, Rep. LA-11971-MS (November 1990).